The atmospheric conditions over Europe and the Mediterranean, favoring snow events in Athens, Greece

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The atmospheric conditions over Europe and the Mediterranean, favoring snow events in Athens, Greece

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Abstract. The 3-dimensional structure and the evolution of atmospheric circulation favoring snowfall in Athens are examined. The study refers to 61 snow events, which occurred during the period 1958–2001. For each one of the events, the patterns of MSL pressure, 850 hPa and 500 hPa air temperatures, 500 hPa geopotential height and 1000–500 hPa thickness are constructed for the European region, for the day before (D-1), the first day (D) and the day after the end of the event (END). A statistical methodology involving Factor Analysis and Cluster Analysis is applied to the above data sets and the 61 cases are finally classified into five clusters. These clusters are generally characterized by a north-easterly flow in the lower troposphere over the Athens area. This flow is associated with the presence of a low pressure system around Cyprus and an anticyclone over Europe. The position, the intensity and the trajectories of the surface and the upper air systems during D-1, D and END days are generally different among the five clusters.

1 Introduction

Scientific research in meteorological forecasting during the last decades has mainly focused on the construction and the improvement of numerical models for weather prediction. These models aim at the prediction of the oncoming weather and the possible occurrence of extreme meteorological events that may cause inconvenience in human activities (e.g. Keller, 2002; Hervella et al., 2003). On the other hand, some researchers have examined the connection between extreme meteorological events and atmospheric circulation by using statistical methodologies (e.g. Metaxas et al., 1993; Romero et al., 1998; Jansa et al., 2001; Kutiel et al., 2001; Kostopoulou and Jones, 2005). In many regions of the Mediterranean basin, snowfall can be considered as an extreme event and it is responsible for significant problems in transportation, cutback on industrial and trade activity, damages to the power supply network and sometimes fatal accidents. The synoptic conditions associated with snowfall in various Mediterranean regions, including Athens, have been studied in the past, by using various approaches (e.g. Prezerakos and Angouridakis, 1984; Tayanc et al., 1998; Esteban et al., 2005). In the present study, the issue of snowfall in Athens is approached by introducing a new objective methodology scheme, in order to identify not only the main circulation patterns associated with the event, but also the details referring to the position, the intensity and the evolution of the associated circulation systems from the day before the beginning till the day after the end of the event.

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2 Data and methodology

The data used consists of: i) 3-hourly meteorological observations recorded at the meteorological station of Hellenikon airport (Athens area), provided by the Hellenic National Meteorological Service and ii) 12:00 UTC 2.5×2.5 grid point data of MSL pressure, 850 hPa and 500 hPa air temperatures, 500 hPa geopotential height and 1000–500 hPa thickness over Europe (10° W–40° E and 30°–60° N) for the period 1958–2001, obtained from the ECMWF ERA40 Reanalysis Project. When at least one, of the 3-hourly observations in a day reports snowfall, this day is considered as a snow day. The sequence of successive snow days is then considered as a snow event. The first day of a snow event will be mentioned as D day, the day before D day as D–1 day and the day that follows the last day as END day. By analyzing the dataset, 61 snow events are extracted. Three matrices are constructed (one for each of D-1, D and END days), containing the grid point values of MSL pressure, 850 hPa and 500 hPa air temperatures, 500 hPa geopotential height and

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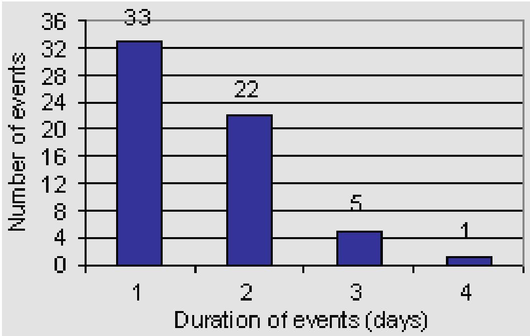

Fig. 1. Distribution of snow events according to their duration.

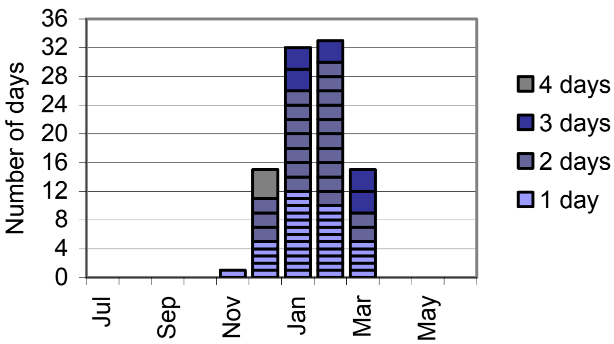

Fig. 2. Number of snow days and duration of snow events per month.

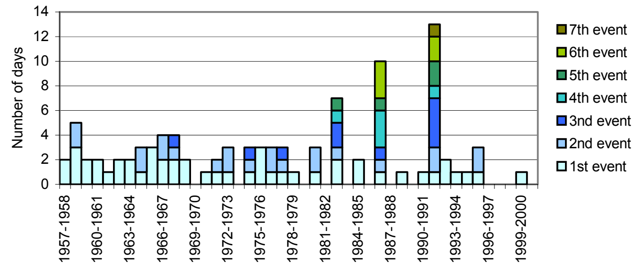

Fig. 3. Number and duration of snow events per winter (November–March).

1000–500 hPa thickness, for the 61 snow events. Thus, each one of the three matrices consists of 61 rows corresponding to the snow events and 1365 columns corresponding to the 273 grid point values of the 5 parameters.

At first, *Factor Analysis* (FA) (Jolliffe, 1986; Manly, 1986) is applied to each one of the three matrices in order to reduce their dimensionality. 11 factors are retained for each case, accounting for at least 85% of the total variance. By unifying the resulted 61×11 matrices, a new 61×33 matrix is constructed. Each row represents the evolution (D-1, D, END days) of the 3-dimensional atmospheric structure associated with the corresponding snow event. Then, *K-Means Cluster Analysis* (CA) (Manly, 1986; Sharma, 1996) is applied to the above 61×33 matrix, classifying the 61 cases into 5 distinct clusters. The number of clusters is selected by testing an hierarchical cluster analysis using Ward's method in order to obtain a general view of the clustering step by step in the corresponding dendrogram. Also, a technique introduced by Sugar and James (2003), based on distortion, a quantity that measures the average distance between each observation and its closest cluster center, is applied confirming our selection. We note, that our purpose is to identify not only the general characteristics of the synoptic conditions favoring snowfall in Athens, but also the details referring to the position, the intensity and the trajectories of the associated circulation systems. For each of the 5 clusters revealed, the mean patterns of the meteorological parameters are constructed for D-1, D and END days, describing the specific evolution of the atmospheric structure, associated with a snow event in Athens.

3 Results

3.1 General characteristics of snow events

More than 50% of snow events that occurred in Athens during the period 1958–2001 lasted for 1 day, while only once did the event last for 4 days (Fig. 1). Only one snow event occurred in November while the others occurred during the months December, January, February and March (Fig. 2). Before 1982, it snowed almost every year, but the yearly frequency and duration of the events were low and short respectively. Since 1982, it does not generally snow every year, but the yearly frequency and duration are higher and longer respectively, especially during the winters of 1982–1983, 1986–1987 and 1991–1992 (Fig. 3). It is noted, that the various climate change models predict a general increase in the frequency and the intensity of the extreme weather events. However, a possible association between climate change and the snowfall change in Athens during the recent decades has to be further investigated.

3.2 Classification of snow events

The 61 snow events are classified into 5 clusters. The monthly distribution of these snow events classified in the 5 clusters (Fig. 4a) shows, that clusters 1, 2 and 5 can be characterized as late winter clusters, as they mainly appear from January to March. On the other hand, clusters 3 and 4 appear mainly during the conventional winter (December–February). According to the duration of snow events of each cluster (Fig. 4b), it is shown that the events classified in clusters 3, 4 and 5 appear to last longer than these of clusters 1 and 2. By examining the inter-annual variation of the events of each cluster (Fig. 4c), it is shown that the events of cluster 1 appear frequently during the whole under study period, but especially during the period 1971–1975. The events of

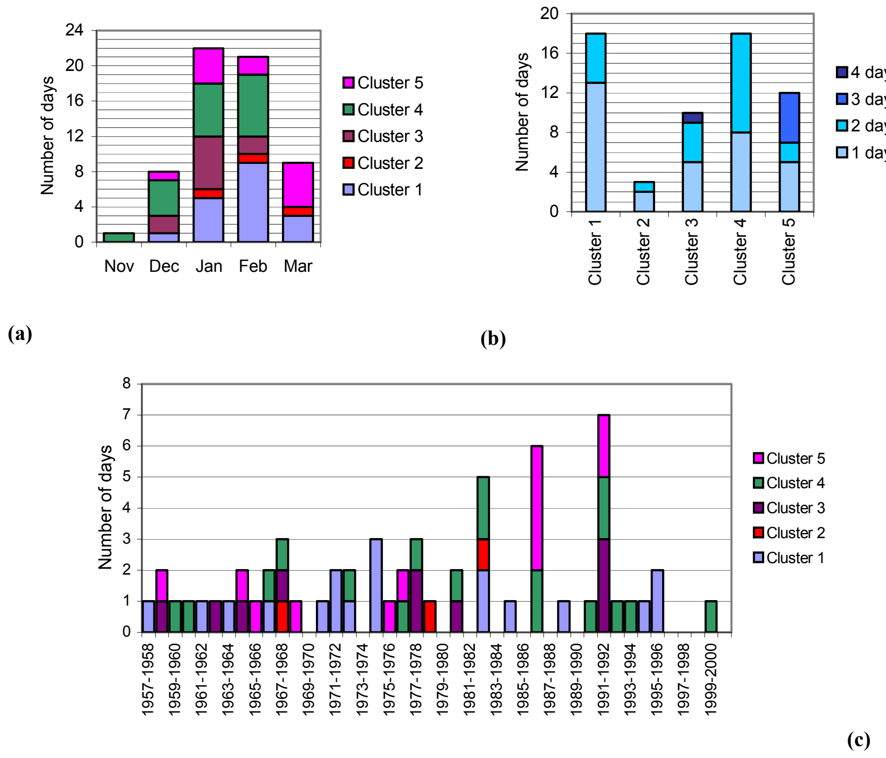

Fig. 4. (a) Monthly distribution, **(b)** duration and **(c)** inter-annual variation of snow events for the 5 clusters.

cluster 3 appear relatively frequently before 1981, but they do not appear at all since 1981, except from the winter of 1991–1992, which is the snowiest winter of the whole period. Also, the events of cluster 5 appear frequently before 1977, but since 1977, they appear only during the winters of 1987–1988 and 1991–1992. Finally, the events of cluster 4 seem to be evenly distributed in the under study period.

In order to examine the time of the initiation of the events, the number of snow events versus the first hour of their report is plotted (Fig. 5). It is shown, that the initiation of the events generally appears to occur in the morning. For a statistical confirmation of this finding, Chi-square test is applied in order to examine whether the diurnal distributions of the initiation hour differ significantly from the uniform one. It is found, that this is valid only for cluster 1 and the total number of the events (95% confidence level). This morning maximum may be connected to the fact that, in the morning, air temperature is lowest and relative humidity is highest, favoring increased condensation. It has to be mentioned that the maximum in diurnal variation of winter precipitation and cloudiness in Athens occurs in the morning also (Karapiperis, 1963; Metaxas, 1970; Catsoulis et al., 1976).

For each one of the 5 clusters, the mean patterns of MSL pressure (hPa), 850 hPa air temperature (°C), 500 hPa air temperature (°C), 1000–500 hPa thickness (m) and 500 hPa geopotential height (m) for D-1, D and END days are presented in Figs. 6, 7, 8, 9, 10.

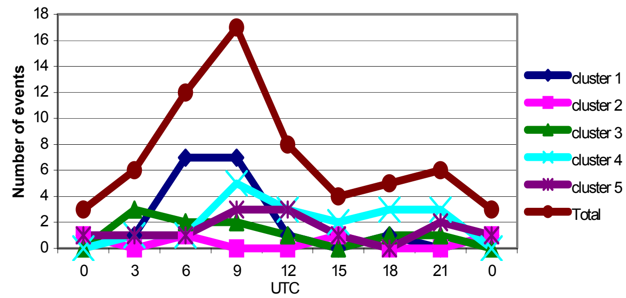

Fig. 5. The number of snow events versus the first hour of their report for each cluster.

Cluster 1 (Fig. 6): During D-1 day, an upper air trough is shown over the eastern Balkans and the Black Sea and a ridge is shown over the western Europe. At the surface, the low pressure center is located over Cyprus and the anticyclone is located over central Europe (depressions tilt towards low temperatures and anticyclones tilt towards high temperatures). The combination between the two systems induces a cold advection over the eastern Balkans, in the middle and the lower troposphere. On D day, the upper air trough moves over the eastern Aegean, the anticyclone moves over the northwestern Balkans and the north-easterly flow is enhanced, leading to a strong cold invasion over

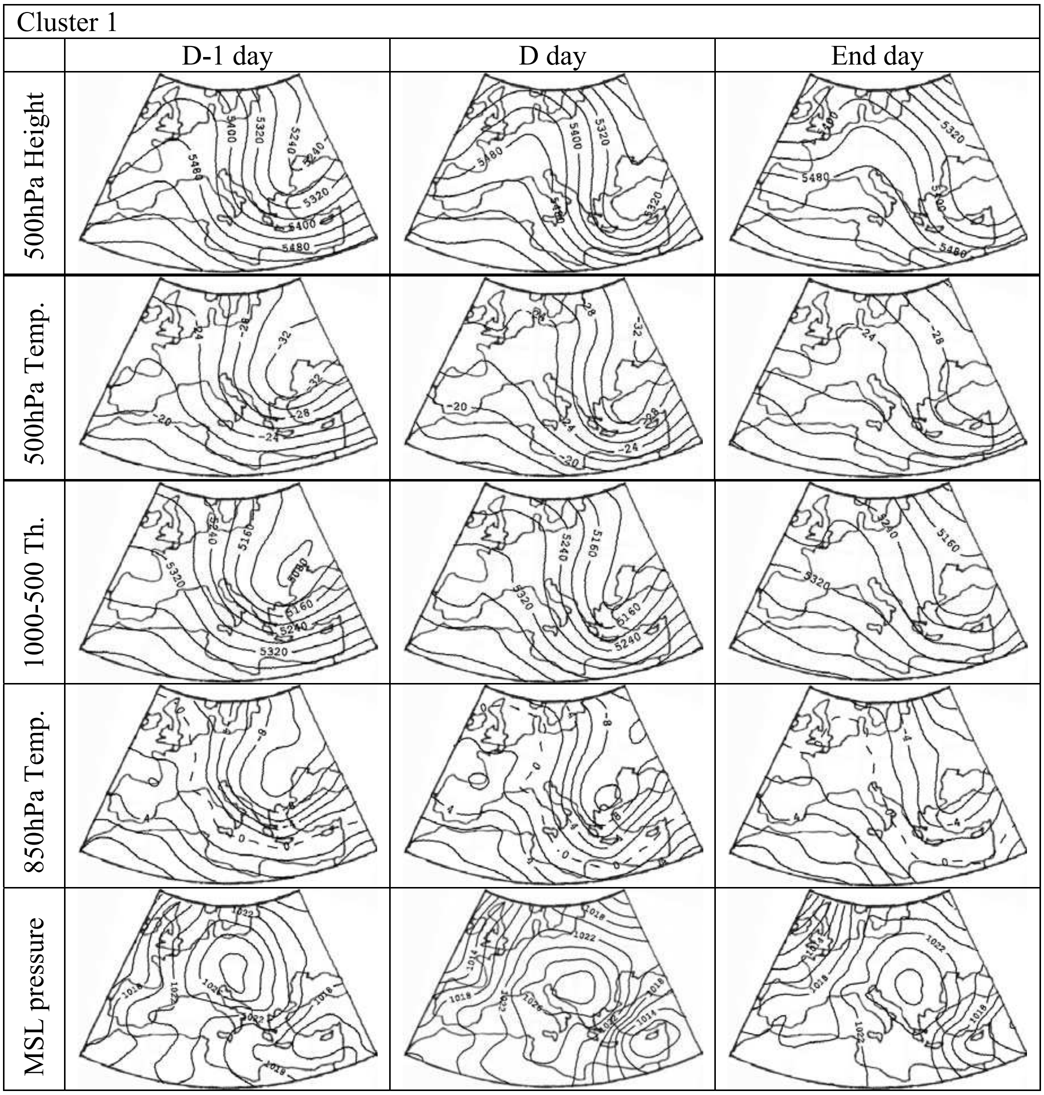

Fig. 6. Mean patterns of MSL pressure (hPa), 850 hPa air temperature (°C), 500 hPa air temperature (°C), 1000–500 hPa thickness (m) and 500 hPa geopotential height (m) for D-1, D and END days, for cluster 1 (18 snowfall events).

Athens, associated with a temperature decrease of about 4°C at 850 hPa level. On END day, the upper air trough and the surface low move eastwards and the surface flow is weakened.

Cluster 2 (Fig. 7): This is the most infrequent cluster, as it comprises only 3 late winter days. During D-1 day, an upper air trough affects Italy, the Adriatic Sea and the northern Balkans and it is associated with a strong north-easterly flow in the lower troposphere over these areas. On D day, the whole system and the associated cold upper air mass move over the eastern Balkans and the Aegean, where the very strong northerly flow is responsible for the advection of very cold air masses in the lower troposphere. This flow is attributed to the combination between an anticyclone over France and a very deep depression over Cyprus. The D day of this cluster is characterized by the lowest air temperatures over Athens among the five clusters (500 hPa: −33°C, 850 hPa: −9°C, 1000–500 hPa thickness: 5080 m), as well as by the deepest Cyprus depression (below 1000 hPa). On END day, the trough and the associated cold mass move over Asia Minor and the Black Sea, while anticyclonic conditions prevail over Greece.

Cluster 3 (Fig. 8): During D-1 day, an upper air trough and a cold air mass are shown over the Balkans, while a combination between an anticyclone over central Europe and a depression between Crete and Cyprus in the lower troposphere is responsible for a north-easterly flow over the same area. During D day, an upper low is formed over the Aegean and west Asia Minor, while the surface anticyclone and the depression move over the northern Balkans and the Cyprus area

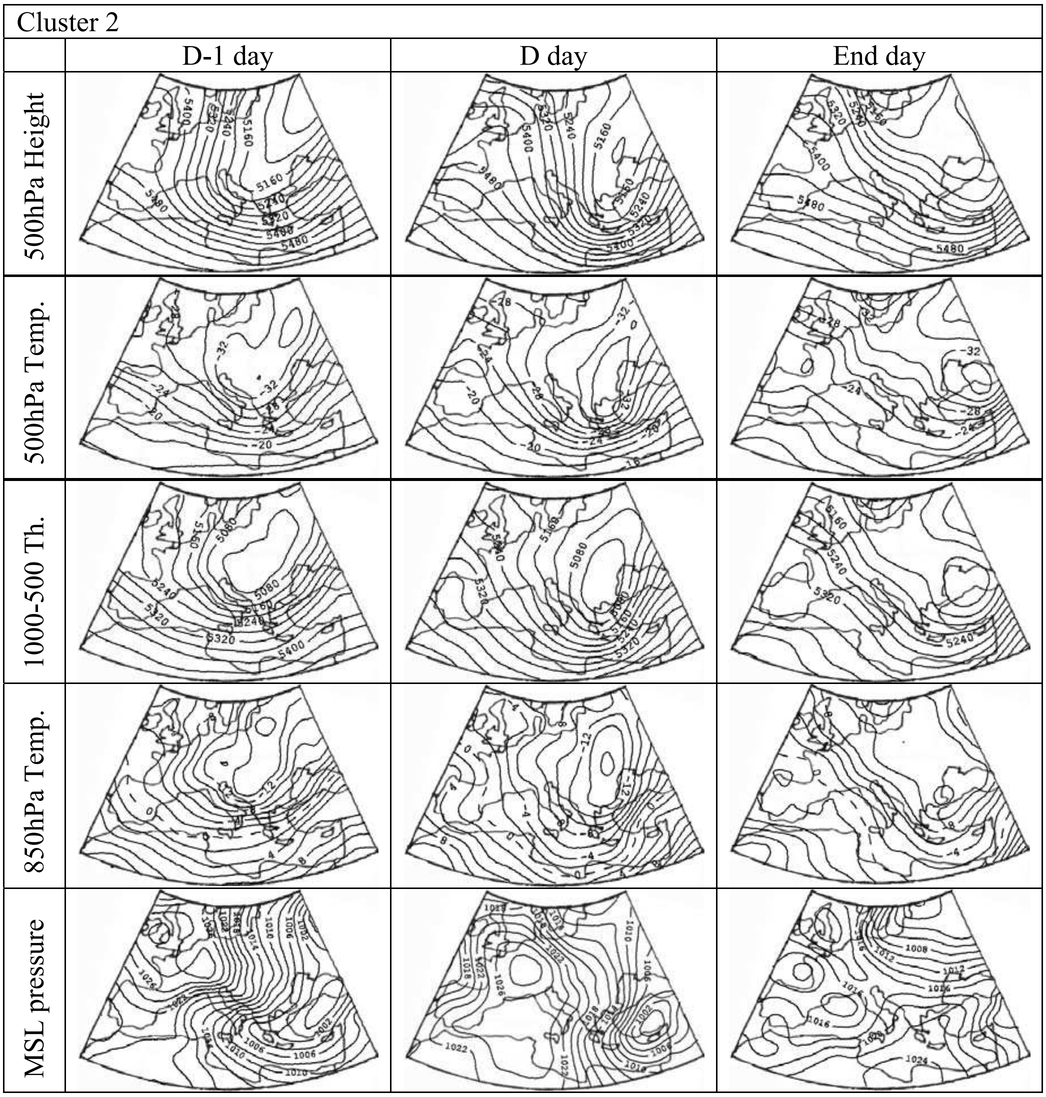

Fig. 7. As in Fig. 6, but for cluster 2 (3 snow events).

respectively causing a very strong north-easterly flow over Greece. On END day, the cold air mass becomes warmer and moves eastwards along with the associated upper air trough and the surface low.

Cluster 4 (Fig. 9): On D-1 day, an upper air trough appears over the northern Balkans, an anticyclone is centered over western Europe and a low pressure system is centered over the area between Crete and Cyprus. During D day, the upper air trough moves over the Aegean, the anticyclone moves eastwards over central Europe and the north-easterly flow over Athens is intensified, transferring cold air masses. This cluster presents the highest temperature in the lower troposphere over Athens, during D day, among all the clusters (850 hPa: −6°C, 1000–500 hPa thickness: 5170 m). During END day, the surface and upper air systems and the north-easterly flow are weakened.

Cluster 5 (Fig. 10): During D-1 and D days, a 500 hPa trough and a cold air mass exist over the Balkans, while a north-easterly flow, associated with an anticyclone over central Europe and a depression between Crete and Cyprus, prevails over the Aegean and the Athens region. On END day, an upper low is formed over the north-eastern Balkans, while the high pressure gradient area in the lower troposphere moves eastwards affecting north-west Asia Minor. This cluster prevails mainly in late winter.

Despite the fact that the D day synoptic conditions of the five clusters seem to be quite similar to each other, it has to be mentioned that each cluster is not characterized by the patterns of D day only, but also by these of D-1 and END days. This means, that each cluster is described by the whole set of 15 patterns corresponding to the five meteorological parameters of the three days. Thus, the individual characteristics

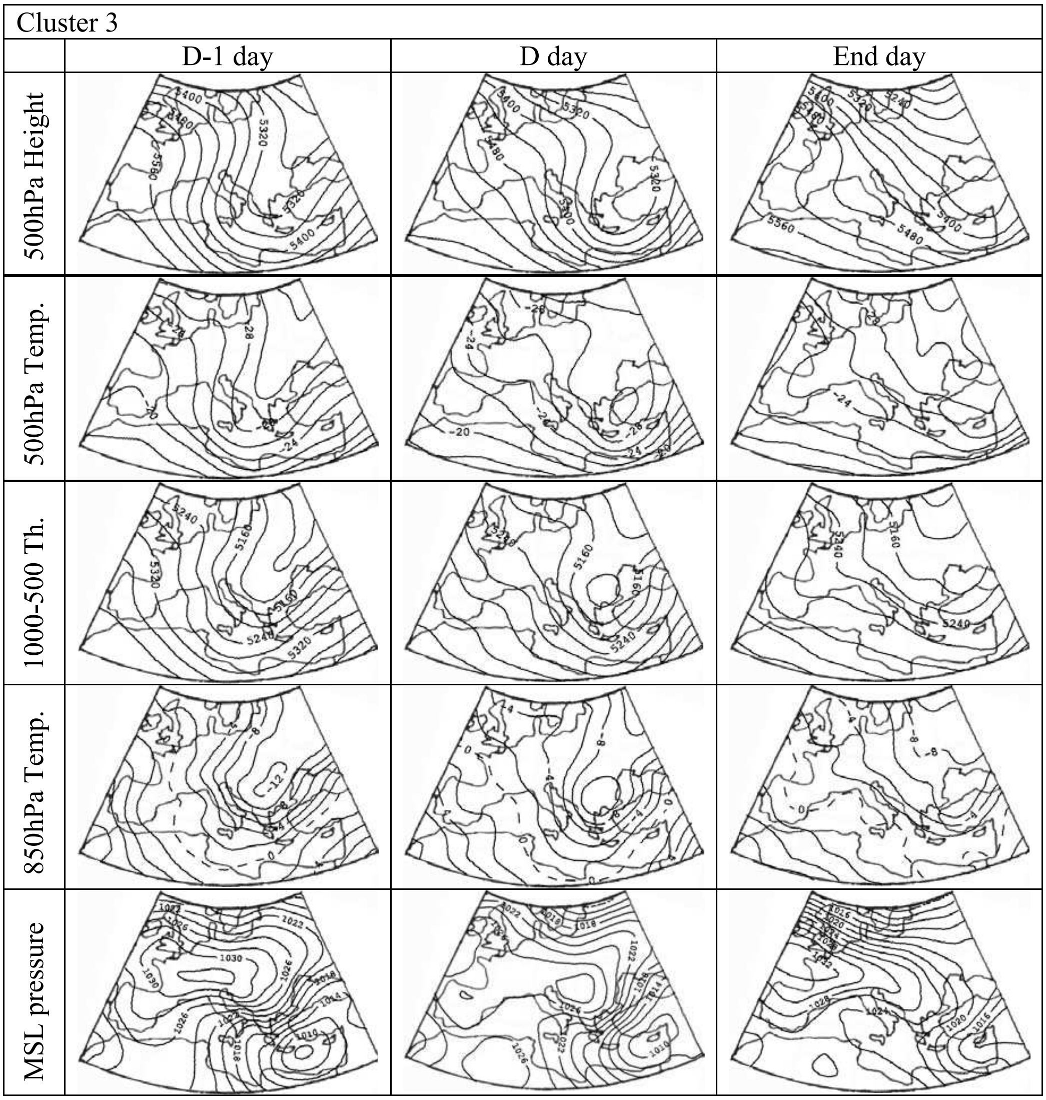

Fig. 8. As in Fig. 6 but for cluster 3 (10 snow events).

Table 1. Average D day values for specific meteorological characteristics of the 5 clusters.

Cluster	500 hPa Temperature over Athens (C)	850 hPa Temperature over Athens (C)	1000–500 hPa Thickness over Athens (m)	Anticyclone center SLP (hPa)	Depression center SLP (hPa)
1	−29	−8	5160	>1028	<1012
2	−33	−9	5080	>1028	<1000
3	−29	−7	5160	>1028	<1010
4	−29	−6	5170	>1030	<1010
5	−31	−7	5160	>1028	<1006

of each cluster may refer to one or two of the three days, or even to some specific patterns of one of the three days only. For example, a specific characteristic of cluster 2 is the very strong MSL pressure gradient over eastern Europe and the Balkans during D-1 and D days, while a specific characteristic of cluster 5 is the formation of an upper low over the eastern Balkans between D and END days. In Table 1, some quantitative features of D day are presented for each cluster.

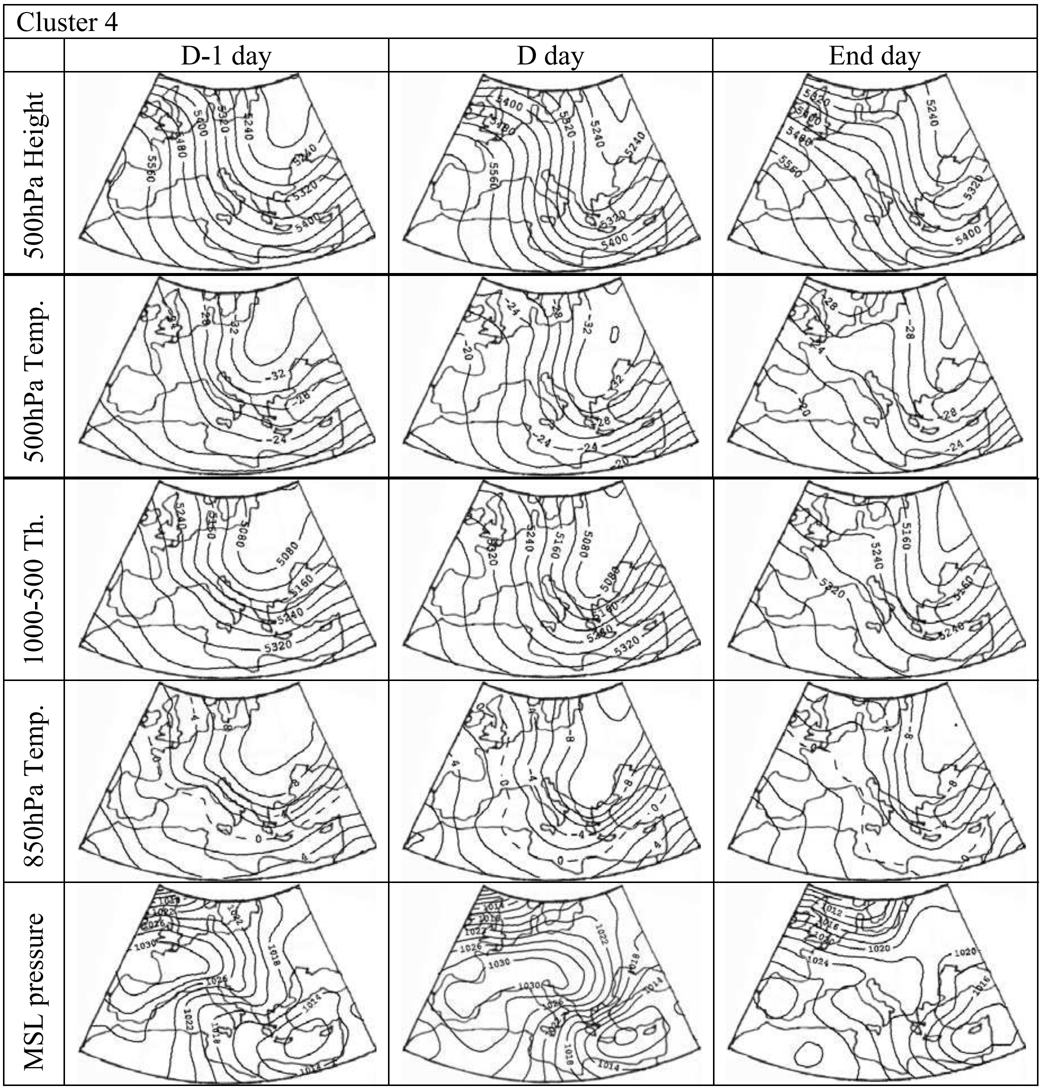

Fig. 9. As in Fig. 6, but for cluster 4 (18 snow events).

4 Conclusions

Snowfall in Athens can be generally considered as a rare event and snowing for more 2 consecutive days is exceptional. The winters of 1982–1983, 1986–1987, and 1991–1992 are the snowiest winters of the period 1958–2001.

The 61 snow events can be classified into 5 clusters. Each distinct cluster describes a specific evolution of the 3-dimensional atmospheric structure over Europe, associated with snowfall in Athens. The main common characteristic among the 5 clusters is a north-easterly surface flow over Athens during D day, associated with the presence of a low pressure system around Cyprus and an anticyclone over Europe. The corresponding air masses arriving in Athens are cold and humid, as they are originated from the continental areas of Eastern Europe and they have passed over the Aegean Sea. The differences among the 5 clusters refer to the specific positions, the intensity and the trajectories of the synoptic systems and the associated cold air masses in the middle and the lower troposphere.

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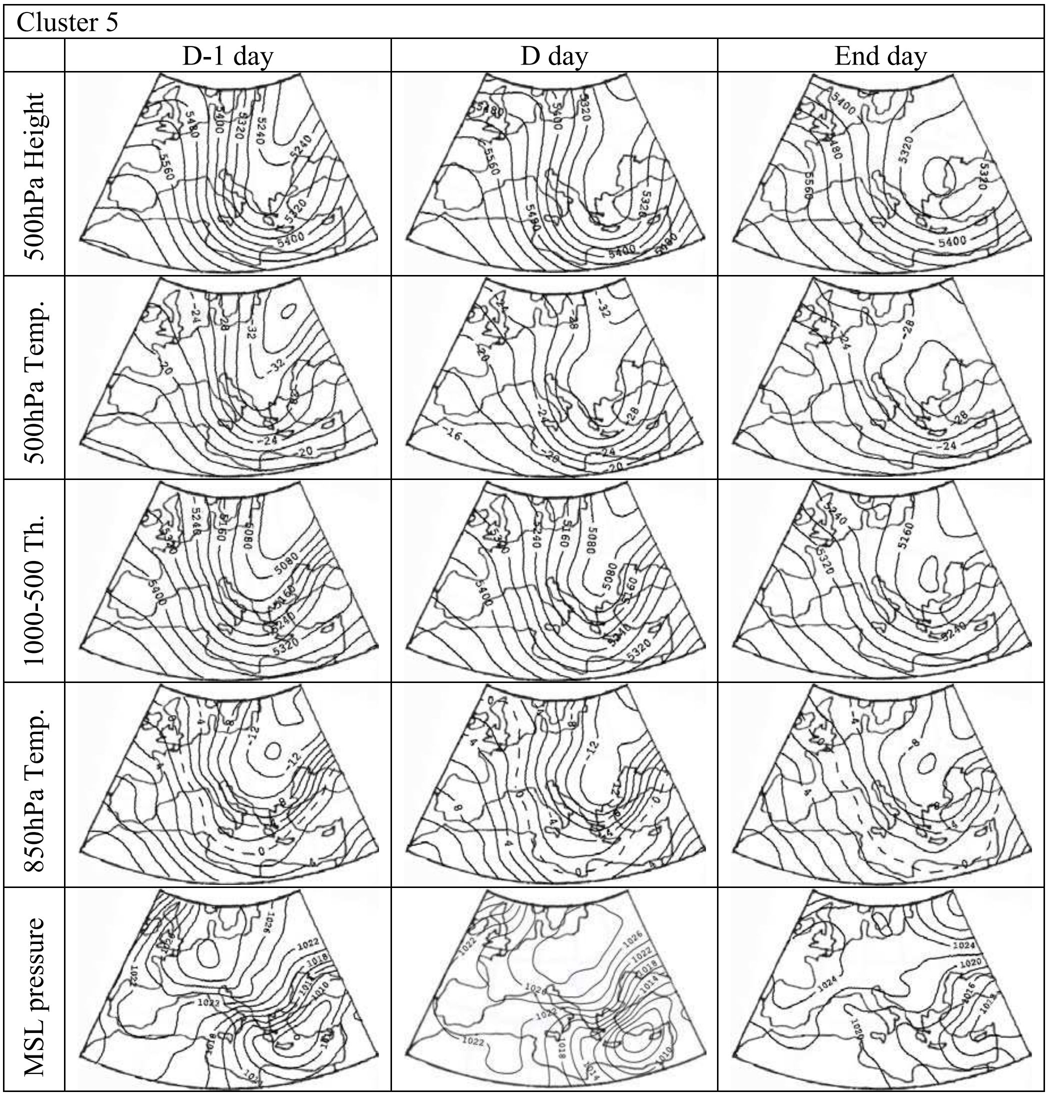

Fig. 10. As in Fig. 6, but for cluster 5 (12 snow events).

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